

Lower limit on the mass of the neutralino (LSP) at LEP with the ALEPH detector

Laurent Serin, on behalf of the ALEPH collaboration

Laboratoire de l'Accélérateur Linéaire

IN2P3-CNRS et Université de Paris-Sud, BP 34, F-91898 Orsay Cedex, France

Abstract

The large amount of data accumulated at LEP2 by the ALEPH experiment has been used to search for supersymmetric particles. No signal has been found therefore limits have been determined. Within the Constrained Minimal Supersymmetric Standard Model, the constraints from direct SUSY searches of charginos, sleptons and neutralinos, are combined to extract a lower limit on the mass of the neutralino considered to be the Lightest Supersymmetric particle. An improved limit is obtained when the limit on the Higgs mass is included. Neutralino masses up to 38 GeV/c² are excluded at 95 % confidence level.

1 Introduction

In many supersymmetric models conserving R-parity, the neutralino as Lightest Supersymmetric Particle, is considered to be a candidate for cold dark matter if its density does not over-close the Universe [1]. Experiments aiming at a direct detection of these Weakly Interacting Massive Particles (WIMP) exist and are summarized in [2]. On the other hand, at accelerator experiment, a lower limit on the mass of the neutralino can be also extracted and results from the combination of direct SUSY searches (charginos, sleptons,...).

First the SUSY model used at LEP to obtain the excluded regions and the strategy to set a lower limit on the mass of the neutralino are discussed. Then the signal and background topologies are explained. The exclusion and the limit on the neutralino mass are shown in section 3, including a discussion of the main sources of theoretical uncertainties. Finally, the impact of Higgs search is presented.

2 Definition of SUSY framework and strategy

Most of the results are interpreted at LEP in the Constrained Minimal Supersymmetric Standard Model (CMSSM) with R-parity conservation and with the assumption of GUT mass unification. In this model a few parameters are enough to describe the properties of SUSY particles :

- m_0 : the common sfermion mass at the GUT scale
- $m_{1/2}$: the common gaugino mass at the GUT scale
- A_0 : the universal trilinear coupling
- $\tan\beta$: the ratio of the two higgs doublet vacuum expectation values
- μ : the higgsino mass parameter

- m_A : the CP-odd Higgs boson mass, relevant for the Higgs sector

The corresponding parameters at the electroweak scale are obtained by solving the Renormalization Group Equations. In practice M_2 is used as a free parameter instead of $m_{1/2}$. From m_0 , M_2 and $\tan\beta$ the slepton masses are derived, with the typical hierarchy : $m_{\tilde{q}} \gg m_{\tilde{\ell}_L} \sim m_{\tilde{\nu}} > m_{\tilde{\ell}_R}$. As an example the slepton right mass can be written as :

$$m_{\tilde{\ell}_R}^2 = \mathbf{m}_0^2 + 0.22\mathbf{M}_2^2 - \sin^2\theta_W M_Z^2 \cos 2\beta \quad (1)$$

The chargino and neutralino masses and couplings are fully specified by M_2 , μ , $\tan\beta$.

If mixing in the scalar sector is not considered, the set of free parameters is reduced to : M_2 , μ , $\tan\beta$, m_0 . A scan over this 4-parameter space is performed to search for the lowest allowed neutralino mass. Two regions, with distinct characteristics depending on the scalar mass m_0 , exist. For large scalar masses, chargino and neutralino limits are used. For low scalar masses, sleptons results must be included. Additional regions are excluded by Higgs constraints, especially for low $\tan\beta$. In order to be conservative, neutralino decays involving Higgs bosons are usually inhibited.

3 Experimental context

Since 1995, the LEP2 e^+e^- collider has regularly increased its center of mass energy beyond the Z resonance. Table 1 shows the luminosity accumulated by ALEPH up to 1999. The results presented in this paper use mainly the data accumulated at and above 189 GeV.

Table 1: Luminosity accumulated by the ALEPH experiment

Year	\sqrt{s}	\mathcal{L}
1995	130-136 GeV	$\simeq 5.7 \text{ pb}^{-1}$
1996	161-172 GeV	$\simeq 21 \text{ pb}^{-1}$
1997	181-184 GeV	$\simeq 57 \text{ pb}^{-1}$
1998	189 GeV	$\simeq 174 \text{ pb}^{-1}$
1999	192-202 GeV	$\simeq 237 \text{ pb}^{-1}$

The main characteristic of SUSY signals is the presence of neutralinos in the final state escaping detection, leading to acoplanar jets, acoplanar leptons or mixed jet/lepton topology. These events have a large missing mass and missing transverse momentum which depends strongly on the mass difference (ΔM) between the produced particle (chargino, slepton or heavy neutralino) and the neutralino (LSP), one of the decay products. Specific analyses have been designed depending on the mass difference and on the final state [3].

The cross section of the main Standard Model backgrounds is presented in Figure 1 :

- For small ΔM , the $\gamma\gamma$ background is typically three orders of magnitude larger than expected signal, but cuts on missing mass or missing transverse momentum reduce this background to a very low level.
- For large ΔM , the QCD background can be easily rejected and the dominant background (WW, $W\nu$ and ZZ) is almost irreducible for some final states.

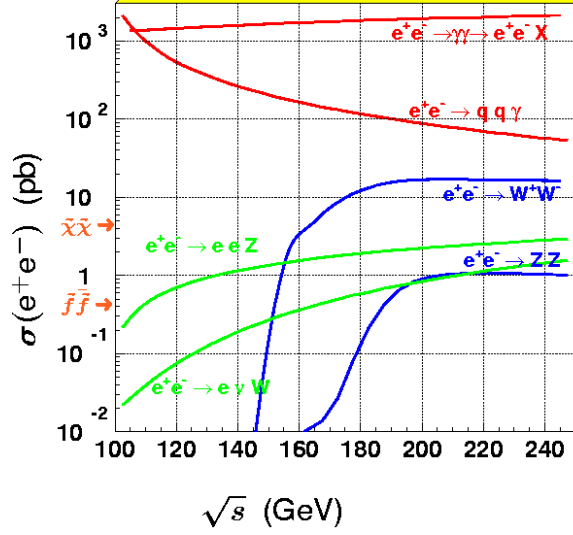


Figure 1: Cross section of Standard Model backgrounds as function of the center of mass energy

4 Excluded region and limit on the neutralino mass

4.1 Sleptons

The sleptons are produced by pair in the s-channel via γ, Z , and in the t-channel via neutralino exchange, leading to an increase of the cross section for selectron production. The final state consists of two leptons and two neutralinos (the efficiency for cascade decays is assumed to be zero). No evidence of a signal was observed, e.g. in the 1999 data, 42 events were observed while 39 were expected from background [4]. The main background comes from leptonic decays of WW events (the WW background is subtracted in all analyses involving at least one lepton). Figure 2 shows the limits obtained in the selectron-neutralino plane. Typically selectron masses up to 95 GeV/ c^2 are excluded. As shown in equation 1, at fixed $\tan\beta$ and for small scalar masses m_0 , this limit can be translated directly on a limit on M_2 .

4.2 Charginos

Charginos are produced in the s-channel via γ, Z and in the t-channel with sneutrino exchange. This two diagrams interfere destructively for low scalar masses resulting in a reduction of the cross section. The decay proceeds via a three-body decay (W^*) or a two-body decay (sneutrino-lepton for instance), leading to final states of 4-jets, 2-jets-lepton, and 2-leptons. A map of the efficiency and background expectation has been computed as a function of ΔM and the leptonic branching ratio. For heavy (light) sfermions, 9 (24) candidates are observed in 1999 data, while the expectation from background is 12.7 (33.9). The chargino exclusion for large scalar masses, shown in Figure 2 reaches the kinematic limit. For low scalar masses, when the chargino and sneutrino are almost mass-degenerate (a few GeV), the final state is practically invisible as the lepton energy, from the chargino decay, is too soft, leading to a non excluded corridor which is displayed on figure 3.

4.3 Neutralinos

In contrast to charginos, the s-channel and the t-channel (via slepton exchange), show a constructive interference, thus an increase of the cross section for low scalar masses. All neutralino production channels ($\chi_1^0\chi_2^0, \chi_1^0\chi_3^0\chi_1^0\chi_4^0\dots$) are taken into account. Final states considered are acoplanar jets and

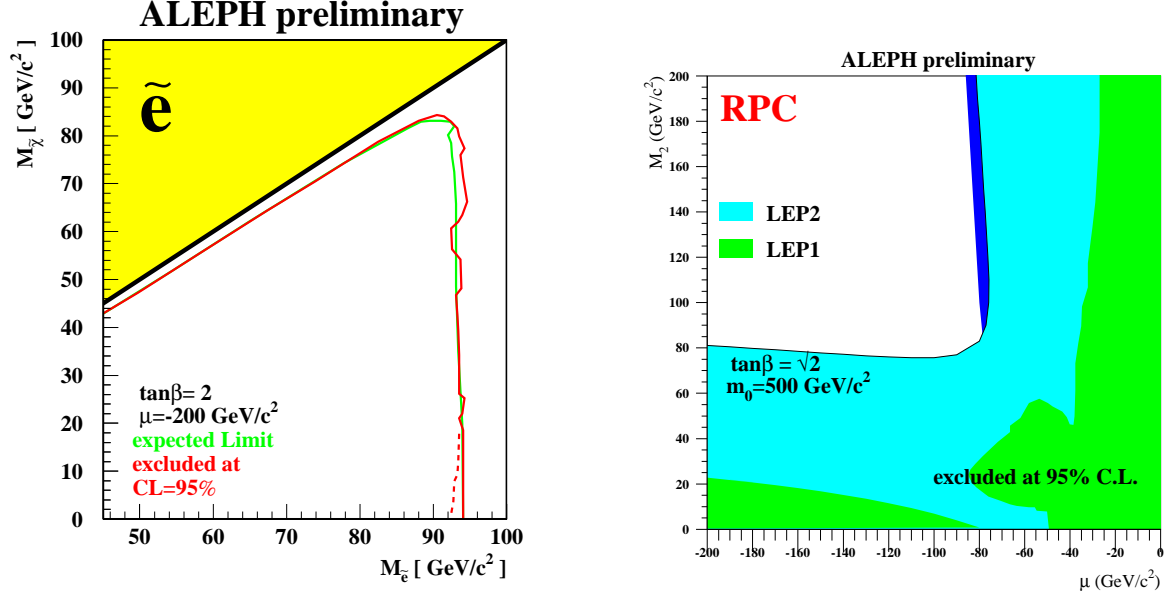


Figure 2: ALEPH limit from selectron search in the selectron-neutralino mass plane. The yellow part is forbidden by theory. (left) and from neutralino and chargino searches for large scalar masses in the (M_2, μ) plane. The dark blue area shows the improvement of the limit with neutralino with respect to chargino exclusion alone (right).

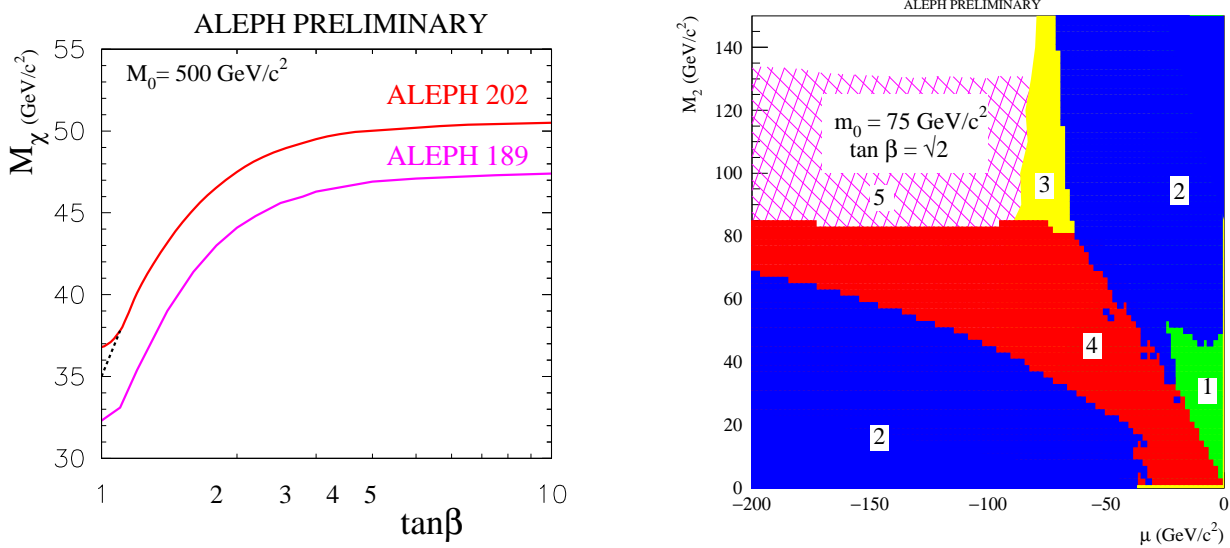


Figure 3: Limit on the neutralino mass for $m_0 = 500$ GeV/c² versus $\tan\beta$. The dashed line shows the limit obtained with charginos only (left). Illustration of the interplay among the various searches for low scalar masses with the 183 GeV data : LEP1 (1), chargino (2), neutralino (3), slepton (4) and Higgs (5). The corridor can be observed between the chargino exclusion in the higgsino and gaugino regions (right).

acoplanar leptons for low m_0 . For heavy (light) sfermions, 5 (78) candidates are observed, while 3.1 (87.7) are expected from background. For large scalar masses, the neutralinos are useful in the higgsino region ($|\mu| > 100$) for low $\tan\beta$ and negative μ as shown in figure 2 as they exclude region above the chargino kinematic limit.

4.4 Limit on the neutralino mass

For large scalar masses the chargino and neutralino exclusions have been combined and Figure 3 shows the limit on the neutralino mass as a function of $\tan\beta$. The limit, given by neutralinos with $\chi_4^0\chi_2^0$ production for $\tan\beta = 1$, is $m_\chi > 37 \text{ GeV}/c^2$ at 95 % CL for $m_0 > 500 \text{ GeV}/c^2$.

To extract the absolute limit obtained for any m_0 , first the chargino and slepton searches are combined via parametrisations of efficiency and maps of background. Then for each $(m_0, \tan\beta)$, for all the points not yet excluded with a neutralino mass $< 38 \text{ GeV}/c^2$, neutralino events are simulated, reconstructed and the analyses applied to determine if the point is excluded. The combined limit is :

$$m_\chi > 35 \text{ GeV}/c^2 \text{ at 95 \% CL for any } m_0 \text{ and } \tan\beta$$

4.5 Uncertainties on the LSP mass limit

A few caveats concerning the robustness of the LSP mass limit should be mentioned :

- The dependence of the limit on the mixing parameters, which induce an enhancement of chargino and neutralino decays to taus, must be studied.
- Radiative corrections to chargino and neutralino masses decrease the limit by about 1 GeV in the region where the limit is found.
- Higher order corrections to the one-loop GUT relation between M_1 and M_2 introduce a variation of a few % on the LSP mass limit.

The typical uncertainty on the LSP mass limit is therefore about 2 GeV.

5 Higgs constraints on the neutralino mass limit

At tree level, the mass of the lightest supersymmetric Higgs, m_h depends only on m_A and $\tan\beta$, and is bounded by $m_Z|\cos 2\beta|$. A limit on m_h therefore gives directly a limit on $\tan\beta$ as soon as m_A is fixed. As the radiative corrections to the Higgs mass introduce a dependence on the stop mass, i.e. the mixing parameter A_t , the picture has to be refined. Fortunately large stop mixing, which means an increase of the Higgs mass, induces also a small stop mass. Using the Higgs constraints for small mixing, and the stop search for large mixing, the exclusion obtained previously in the (M_2, μ) plane can be substantially improved for low m_0 and $\tan\beta$. A scan over all possible values on m_A and A_t within the physical ranges is performed to obtain this limit. As an illustrative example, the improvement is shown in figure 3 at 183 GeV. To update the results for a higher center of mass energy, the stops constraints are no longer useful and the $(\tan\beta, m_0, M_2, \mu)$ plane is scanned with the following procedure [5] :

- It has been shown that the dependence of the limit with μ is negligible, the value has been fixed to $-100 \text{ GeV}/c^2$ where m_h is maximal.
- m_A has been fixed to $2 \text{ TeV}/c^2$ to maximize m_h . A scan over A_t is performed to determine the highest value of m_h in each point, which is compared to the ALEPH Higgs mass limit on m_h ($107.7 \text{ GeV}/c^2$) ($m_t = 175 \text{ GeV}/c^2$ is used).

- The Higgs mass limit, if the radiative corrections are small, can be translated into a limit on $\tan\beta$. In the other case, this limit can be translated into a limit on the stop mass, and therefore into a limit on M_2 (assuming m_0 is not too large).

Figure 4 summarizes the exclusion obtained in the $(M_2, \tan\beta)$ plane from the Higgs limit. Any value of $\tan\beta < 1.7$ is excluded. When increasing $\tan\beta$ up to about 3, a lower limit on M_2 is obtained for small scalar masses (typically $< 200 \text{ GeV}/c^2$). The result of the combination of the Higgs constraint with the previous limit on the neutralino mass is shown in Figure 4. Low $\tan\beta$ are excluded by Higgs constraints and supersedes the chargino/neutralino limit. However this limit is very sensitive, through the radiative corrections, to the top mass. If $m_t = 180 \text{ GeV}/c^2$, this exclusion do not hold, but a $40 \text{ GeV}/c^2$ neutralino mass is always excluded when $\tan\beta < 3$. If furthermore m_0 is taken to be $2 \text{ TeV}/c^2$, no more limit from Higgs can be used. Then the limit is given by the charginos exclusion at large scalar masses in a tiny region of $\tan\beta$. Finally increasing with $\tan\beta$, the neutralino limit is found in the corridor where charginos and neutralinos can not help. For $\tan\beta > 3$, only the slepton search contributes and the absolute limit is :

$$m_\chi > 38 \text{ GeV}/c^2 \text{ at } 95 \% \text{ CL for any } m_0 \text{ and } \tan\beta$$

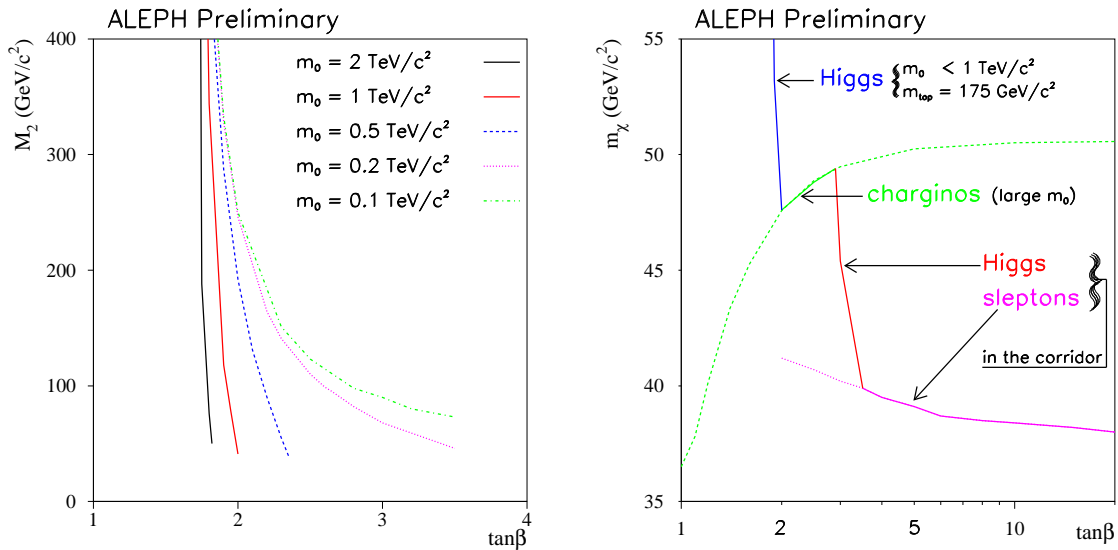


Figure 4: Higgs constraints in the $(M_2, \tan\beta)$ plane (left), and limit on the neutralino mass combining chargino, neutralino, slepton and Higgs constraints versus $\tan\beta$ (right)

6 Conclusion

Using the large amount of data accumulated at LEP2 by ALEPH, the combination of direct searches of SUSY particles can be used to extract a lower limit on the mass of the neutralino, as the Lightest Supersymmetric particle. A lower limit of $35 \text{ GeV}/c^2$ on the neutralino mass is obtained for any scalar mass m_0 and $\tan\beta$. Moreover, a limit of $38 \text{ GeV}/c^2$ is obtained including the Higgs constraints. At the end of LEP operation, a value of at least $40 \text{ GeV}/c^2$ should be reached if no signal is observed.

References

- [1] J. Ellis, T. Falk, G. Ganis, K. A. Olive, CERN-TH/2000-106 (2000)
- [2] More details on the existing and future experiments in this domain can be found in these proceedings
- [3] ALEPH coll., *Euro. Phys. J.* **C11** (1999) 193.
- [4] ALEPH Coll., ALEPH note for 2000 winter conference 2000, ALEPH 2000-012, CONF 2000-009
- [5] ALEPH coll., ALEPH note for 2000 winter conference 2000, ALEPH 2000-019, CONF 2000-016
J.B. De Vivie, Phd Thesis, Université de Paris Sud Orsay, LAL-00-11, Apr 2000

